ITEM 11

City of Santa Barbara
Public Works Department

Interoffice Memorandum

DATE: October 8, 2009

TO: Board of Water Commissioners

FROM: Rebecca Bjork, Water Resources Manager BF for

SUBJECT: USGS Contract for Optimal Groundwater Sustainability Project

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Attached for discussion at our October 12, 2009 meeting is a description of work proposed under a joint cooperation agreement with USGS for an update of the City's groundwater modeling and Multiple Objective Optimization Model. This is a substantial work effort, planned over three years, and reflects the importance of our groundwater resources in terms of drought water supply, emergency local supplies during catastrophic interruption of other water supplies, and leveraging groundwater to help offset high costs associated with operating the water system. The last work on this subject was completed during the late 1980's drought and subsequent Long Term Water Supply Program planning effort.

The City's share of costs would be $345,400 spread over three years and we expect to be able to take advantage of approximately $171,000 of USGS contributions as shown in the attached material. We look forward to a discussion of this project with the Commission.

BF/bf

Attachment

(8/24/2004)

PROJECT PROPOSAL COVER SHEET

WRD REGION: Western	**PROPOSAL NUMBER:** CA07_
CAWSC OR PROJECT OFFICE: California	**DATE (Initial):**
PROJECT TITLE: Optimal Groundwater Sustainability, Santa Barbara, California	**DATE (Revised):**
	PROJECT NUMBER:
SHORT TITLE:	**BEGIN DATE: (mo/yr)**
PROJECT CHIEF:	**END DATE: (mo/yr)**

Choose one: RESEARCH RESOURCE APPRAISAL

DISCIPLINE: ground-water quantity ____%, surface-water quantity ____%, ground-water quality ____%, surface-water quality ____%; or (exclusively) administration ____%

A project is either *technical* or *administration*, it cannot be a mix of both.
***Technical* percentages, *if used*, must total 100%. *Administration*, if used, must be 0 or 100%.**

PUBLICATION TYPE:

Scientific Investigative Report (SIR): ______
Journal Article: ______
Abstract: ______
Open File Report (OFR): ______
Letter: ______
Poster: ______
Fact Sheet: ______
Professional Paper: ______
Other (specify) ______
Data Series: ______
Book Chapter: ______

ESTIMATED PROJECT FUNDING

Choose one: firm probable questionable

CUSTOMER NAMES(S)/NUMBER(S): ____________________

FISCAL YEAR	200_	200_	200_	200_	200_
OFA/FEDERAL	$	$	$	$	$
COOP REPAY	$	$	$	$	$
COOP DIRECT	$	$	$	$	$
COOP UNMATCHED	$	$	$	$	$
COOP TOTAL	$	$	$	$	$
FMFs:	$	$	$	$	$
TOTAL FOR FY:	$	$	$	$	$

REMARKS:

AUTHOR:		, 200_
CAWSC ENDORSEMENT:		, 200_
REGIONAL ENDORSEMENT:		, 200_
APPROVED BY:		, 200_

SUMMARY

Title: Optimal Groundwater Sustainability, Santa Barbara, California

Cooperating Agency: City of Santa Barbara

Project Chiefs: Tracy Nishikawa

Problem: Prior to 1997, local surface water and groundwater supplied all of the water supply for the city of Santa Barbara (about 120 miles northwest of Los Angeles). Excess pumping of groundwater during times of drought resulted in saltwater intrusion in Storage Unit I of the Santa Barbara groundwater basin. Since 1997, State Water Project (SWP) water has been delivered to the city, which has reduced the demand for groundwater. However, future urban growth, limits on the supply of imported water, and the decreased storage capacity of Gibraltar Reservoir due to sedimentation will increase the future demand for groundwater, especially during times of drought. There is a need to readily update the potential yield of the local groundwater basins in order to optimally utilize the available water-resources during periods of drought.

Objective: The objectives of this study are to: (1) understand the dynamic sustainability of the groundwater system; (2) develop tools that will continually update information regarding the city's sustainable groundwater supply; and (3) identify optimal water-resource management strategies.

Relevance and Benefits: The benefits to the cooperator are that they will learn about the potential impacts of water-management strategies; gain an updated ground-water flow and solute-transport model that can be used to more efficiently manage the water resources; and gain an updated simulation-optimization model of Storage Units I, III and the Foothill Basin. The proposed study addresses USGS science strategy directions "A Water Census of the United States" and "Climate Variability and Change".

Approach: This study will consist of five phases: (1) update and refine the existing three-dimensional groundwater flow model to include density-dependent solute transport; (2) update and refine the existing simulation-optimization model; (3) develop empirical decision rules that describe the relationship between water levels and chloride concentrations at key wells with sustainable yield; (4) and (5) present the results in an interpretive report(s).

Optimal Groundwater Sustainability, Santa Barbara, California

Problem

Prior to 1997, groundwater and local surface water supplied all of the water supply for the city of Santa Barbara (about 120 miles northwest of Los Angeles). Excess pumping of groundwater during times of drought resulted in saltwater intrusion in Storage Unit I of the Santa Barbara groundwater basin. Since 1997, State Water Project (SWP) water has been delivered to the city, which has reduced the demand for groundwater. However, future urban growth, limits on the supply of imported water, and the decreased storage capacity of Gibraltar Reservoir due to sedimentation will increase the future demand for groundwater, especially during times of drought. There is a need to readily update the potential yield of the local groundwater basins in order to optimally utilize the available water-resources during periods of drought. A primary question is: what are optimal conjunctive-use strategies that will recharge the groundwater system, meet water-supply demands, and control seawater intrusion? In addition, the city of Santa Barbara has posed the following questions: (1) what is the sustainable yield of the groundwater basins; (2) how can the "fullness" of the aquifers be defined and can it be easily quantified without the use of a model; (3) how can the unreported pumping in the Foothill Basin be estimated; and (4) can the location of the seawater front be explicitly estimated?

Objectives

The objectives of this study are to: (1) understand the dynamic sustainability of the groundwater system; (2) develop tools that will continually update information regarding the city's sustainable groundwater supply; and (3) identify optimal water-resource management strategies.

Relevance and Benefits

The benefits to the cooperator are that they will learn about the potential impacts of water-management strategies; gain an updated groundwater flow and solute-transport model that can be used to more efficiently manage the water resources; and gain an updated simulation-optimization model of Storage Units I, III and the Foothill Basin. The proposed study addresses USGS science strategy directions "A Water Census of the United States" and "Climate Variability and Change".

The proposed study also addresses the following elements of the California Water Science Center Science Plan:

Topic I: Water Availability and Supply Reliability

Issue 1-1: Geohydrologic characterization of ground-water basins

Issue 1-2: Aquifer storage and recovery

Issue 1-3: Efficient integrated management of surface water and ground water

Topic II: Water Quality

Issue 2-1: Redirecting wastewater

Issue 2-9: Seawater intrusion

Approach

This study will consist of five phases: (1) update and refine the existing three-dimensional groundwater flow model to include density-dependent solute transport; (2) update and refine the existing simulation-optimization model; (3) develop empirical decision rules that describe the relationship between water levels and chloride concentrations at key wells with sustainable yield; (4) and (5) present the results in an interpretive report(s).

Phase 1: Update and Refine Groundwater-Flow Model

This phase of the study will update and refine the groundwater-flow model by Freckleton and others (1997). Three tasks will be completed as part of this phase: (1) compile and collect available data; (2) update the existing groundwater-flow model; and (3) add the ability to simulate explicitly seawater intrusion (i.e. density dependent solute transport) to the groundwater-flow model.

Task 1: Collect and Compile Data

As part of this task, new and existing data will be collected and compiled. Water-quality and water-level data will be uploaded to the USGS National Water Information System (NWIS) on California Water Science Center computers. Other data types will be compiled in a Geographic Information Systems (GIS) database. Water-level and pumping data will be compiled by well and on a monthly basis. These data will be used to update the existing groundwater flow model. These data will be entered into a GIS database.

Task 2: Update Existing Groundwater-Flow Model

The groundwater-flow model developed by Freckleton and others (1997) was based on MODFLOW-88 (McDonald and Harbaugh, 1988). The model by Freckleton and others (1997) simulated groundwater flow in Storage Units I and III and Foothill Basin. This model will be updated using MODFLOW-2000 (Harbaugh, 2000) and calibrated using water-level data compiled in Task 1. MODFLOW-2000 is an updated version of MODFLOW-88 with improved coding and other improvements such as the ability to address explicitly vertical anisotropy using vertical hydraulic conductivity.

One of the primary data inputs to MODFLOW are stresses which include pumping. In the Foothill Basin there is unreported agricultural pumping which may be a large percentage of the pumpage in this basin (William Ferguson, city of Santa Barbara, personal commun., 2009). For this project, the Farm Process (Schmid and others, 2006) will be used to estimate the unreported agricultural pumpage. The Farm Process is physically based, i.e., it estimates unreported pumping on the basis of crop type, climate, etc. and has been applied successfully in California's Central Valley (Faunt, 2009).

Task 3: Simulate Seawater Intrusion

A primary concern of the city is seawater intrusion induced by groundwater pumping. MODFLOW cannot address density-dependent solute transport, such as seawater intrusion. Freckleton and others (1997) used an equivalent freshwater head as a boundary condition to simulate the hydraulic effects of seawater but the three-dimensional simulation of seawater intrusion in Storage Unit I has not been attempted. To explicitly simulate seawater intrusion, SEAWAT-2000 (Langevin and others, 2007) will be used. SEAWAT-2000 couples MODFLOW-2000 with MT3DMS (Zheng and Wang, 1999) and addresses density-dependent flow and transport (Langevin and others, 2007). Historical chloride data and new chloride data compiled as part of Task 1 will be used to calibrate the SEAWAT-2000 model. A two-dimensional solute-transport model developed for Storage Unit I (Nishikawa and Martin, 1998) will be used to determine the vertical layering needed to adequately simulate seawater intrusion.

Phase 2: Update and Refine Existing Simulation-Optimization Model

Nishikawa (1998) developed a simulation-optimization model for the management of the city's water resources. The simulation model was that developed by Freckleton and others (1997). Specifically, the simulation-optimization model addressed water deliveries from Cachuma and Gibraltar Reservoirs, the State Water Project (SWP), the desalination plant, and city production wells assuming drought conditions. The management problem was formulated as a linear programming problem and was solved using sequential linear programming.

The SEAWAT-2000 model developed in Phase 1 will be used in the updated simulation-optimization model. Density-dependent solute transport is inherently nonlinear; therefore, a linear programming approach will not be appropriate. A traditional solution approach is to solve the nonlinear problem using nonlinear programming techniques; however, these techniques are computationally slow because the gradients must be calculated. In this work, it is proposed to use a global-optimization method which does not require the gradients to be calculated. These methods include genetic algorithms, simulated annealing, and tabu search; the most appropriate method will be determined as part of this study. A genetic algorithm, based on the concept of the survival of the fittest, has been applied successfully to a nonlinear, mixed-integer programming problem by the USGS (Chiu et al., in review).

Phase 3: Develop Preliminary Operating Rules

A key question posed by the city is given a metric (e.g. chloride concentration and/or water level), how much water can be pumped from a particular subbasin without resulting in adverse affects such as dewatering wells or causing excessive chloride concentrations at selected wells? The preliminary simulation-optimization model developed in Phase 2 will be used to answer this question for each subbasin individually assuming a one-year management horizon. To answer this question for Storage Unit I, various chloride distributions and associated water levels will be assumed or estimated for a set of key monitoring wells. The objective will be to maximize pumping for production wells in Storage Unit I and the constraints will include pumping capacity and chloride concentrations at other key wells in Storage Unit I. For each assumed initial chloride distribution, the optimization problem will be solved for varying chloride-concentration constraints (e.g., 10, 25, 50, and 75 percent chloride). This will yield a family of curves that define the maximum amount of pumping for a given initial chloride-concentration distribution and chloride-concentration constraints.

To answer this question for Storage Unit III and the Foothill basin, the objective will be to maximize pumping and the constraints will include pumping capacity and allowable hydraulic heads at specified wells. The allowable hydraulic head will be varied with the minimum value equal to the middle elevation of the perforated interval of the shallowest production well in a subbasin. This constraint will be determined after consultation with city personnel. This will yield a family of curves that define the maximum amount of pumping for a given allowable hydraulic-head constraint.

Phase 4: Simulation-Optimization Under Climate Variability

The goal of this phase is to apply the simulation-optimization model assuming climate variability. This will give the city water-management strategies for varying climates. Two tasks will be completed as part of this phase: (1) analyze precipitation data and (2) develop water-management strategies based on the analysis from task 1.

Task 1: Analyze Precipitation Data

Long-term, annual precipitation data will be compiled for one or more locations in the Santa Barbara area. The cumulative departure from the mean will be calculated for each dataset and wet and dry periods will be identified. Specifically, an average "dry-wet-dry" and an extreme (i.e. low probability) climate cycles will be identified. In addition, the transition probabilities (e.g. "if I'm in a drought this year, what is the probability that a drought will occur next year?") will be calculated.

The sustainable yield and "fullness" of Storage Unit I are a function of the history of groundwater pumping and recovery. For example, under nonstressed conditions, water levels in Storage Unit I can be 10 ft above sea level; however, under stressed conditions the water levels in Storage Unit I can be 100 ft or more below sea level. It is under stressed conditions, with the resulting low water levels, that seawater intrusion occurs. In addition, water levels recovery quickly to nonstressed conditions after the cessation of pumping; however, a quickly recovered water level does not imply that any seawater intrusion that occurred during the pumping period has been reversed because the reversal of seawater intrusion is a slow process. A climatic cycle of a long dry period, followed by a short wet period, followed by another dry period would result in a lower sustainable yield and fullness than a long dry period, followed by a long wet period, followed by another dry period because the first cycle would not allow sufficient time for the reversal of the seawater intrusion during the wet period even though water levels may recover. Therefore, one could not pump as much groundwater during the second dry period of the first "long-short" cycle as opposed to the "long-long" cycle which affects the sustainable yield and the basin fullness.

Task 2: Develop Water-Management Strategies

The average and extreme climatic cycles and transition probabilities identified in Task 1 will be used with the simulation-optimization model to develop water-management strategies. The optimization problem will be formulated with close consultation with city personnel. Potential objectives include minimize water-delivery costs or maximize pumping. Constraints include meeting water demand, pumping capacity, surface-water availability (this may include transition probabilities), etc. The climate cycles will be addressed by surface-water availability. In addition to climate variability, climate change may result in increasing sea levels (more than 3 ft in 100 years) and can also be addressed using the simulation-optimization model by changing the boundary condition at the ocean.

Phase 5: Reports

The project will require 3 years to complete. Quarterly updates will be provided and in-person presentations will be made as needed. In addition, a project webpage will be developed where the quarterly updates will be posted, links to data, and other information will be available to the public. A Scientific Investigations Report (SIR) and a journal article will be prepared at the end of the project. The SIR will document the water-level and water-quality data and describe the development of the models. The journal article will integrate information from all aspects of the project and present the results from the simulation-optimization model. Completion of this article is planned for the end of the project in early FY2013. Publication will be pending review and acceptance of the selected journal.

BUDGET

Table 1: Federal Fiscal Year 2010-12 Budgets

Management Category	2010		SB	USGS	SB	USGS	Total
	SB	USGS	FY-2011	FY-2011	FY-2012	FY-2012	
Phase 1: SEAWAT	$102,500	$50,000					$152,500
Phase 2: Update Sim-Opt	$31,000	$15,000	$13,400	$6,000			$65,400
Phase 3: Decision Rules			$58,000	$30,000			$88,000
Phase 4: Mgt. Strategies			$64,000	$33,000	$15,500	$7,000	$119,500
Phase 5: Reports					$61,000	$30,000	$91,000
Total	$133,500	$65,000	$135,400	$69,000	$76,500	$37,000	$516,400

Personnel

Required personnel include: Yung-Chia Chiu (GS-11 groundwater modeler), Steven Predmore (GS-12 geographer), Joseph Hevesi (GS-12 climate-data analysis), Dennis Clark (GS-11 hydrologist), and Tracy Nishikawa (GS-13 groundwater modeler and project chief).

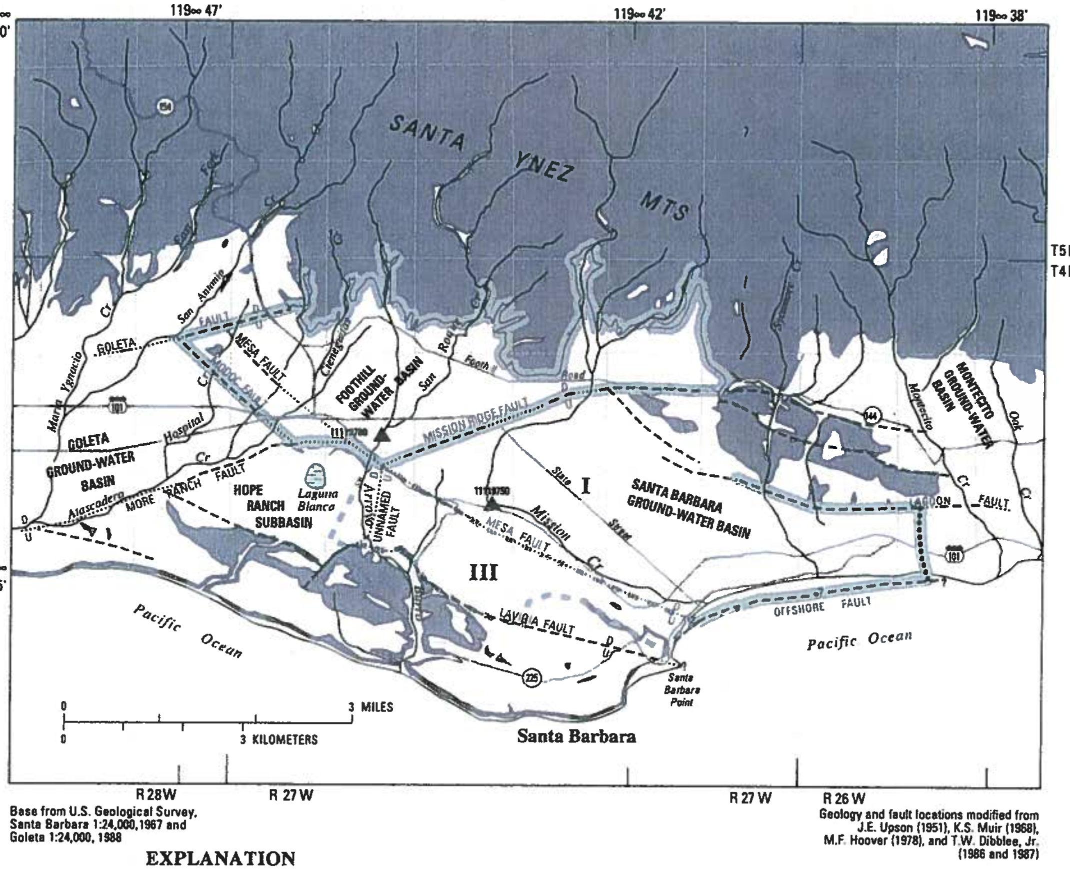
List personnel needs by disciplines, approximate grades, full or part time, and availability of these personnel. Identify planned staffing from outside of WRD.

WORK PLAN

The study will require three years to complete. The work plan is as follows:

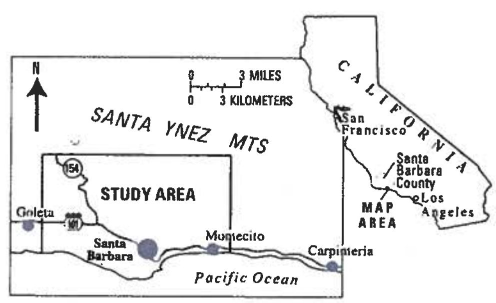
Fiscal year....................	FY-2010	FY-2011	FY-2012
Quarter	F W S S	F W S S	F W S S
Phase 1: Update groundwater model			
Task 1: Compile data	x -- -- --	-- -- -- --	-- -- -- --
Task 2: Update groundwater model	x x x --	-- -- -- --	-- -- -- --
Task 3: SEAWAT	-- -- x x	-- -- -- --	-- -- -- --
Phase 2: Update sim-opt model	-- -- -- x	x -- -- --	-- -- -- --
Phase 3: Develop prelim rules	-- -- -- --	-- x x --	-- -- -- --
Phase 4: Sim-opt under climate variability			
Task 1: Analyze precip data	-- -- -- --	-- -- x --	-- -- -- --
Task 2: Devel water-mgt strategies	-- -- -- --	-- -- x x	x -- -- --
Phase 5: Report preparation			
Prepare annotated outline	-- -- -- --	-- -- -- x	-- -- -- --
Prepare first draft	-- -- -- --	-- -- -- --	x x -- --
Report preparation	-- -- -- --	-- -- -- x	x -- -- --
Colleague review	-- -- -- --	-- -- -- --	-- -- x --
Approval and submission to journal	-- -- -- --	-- -- -- --	-- ---- x

MAP



EXPLANATION

- Unconsolidated deposits
- Consolidated rocks
- Geologic contact
- Fault- Dashed where approximately located; queried where doubtful; dotted where concealed. U, upthrown side; D, downthrown side
- Ground-water divide
- Boundaries-
  - Ground-water basin
  - Storage unit
- III Ground-water storage unit number
- 11119750 Stream-gaging station and identifier



Literature Cited

Chiu, Y.C., Nishikawa, Tracy, Martin, Peter, in review, Hybrid optimization algorithm for the management of a conjunctive-use project and well field design.

Faunt, C.C. ed., 2009, Ground-Water Availability of California's Central Valley: U.S. Geological Survey Professional Paper 1766, 225 p.

Freckleton, J.R., Martin, Peter, and Nishikawa, Tracy, 1997, Geohydrology of Storage Unit III and a Combined Flow Model of the Santa Barbara and Foothill Ground-Water Basins, Santa Barbara, California: U.S. Geological Survey Water-Resources Investigations Report 97-4121, 80 p.

Harbaugh, A.W., Banta, E.R., Hill, M.C., and McDonald, M.G., 2000, MODFLOW-2000, The U.S. Geological Survey Modular Ground-Water Model–User Guide to Modularization Concepts and the Ground-Water Flow Process: U.S. Geological Survey Open-File Report 00-92, 121 p.

Langevin, C.D., Thorne, D.T., Jr., Dausman, A.M., Sukop, M.C., and Guo, Weixing, 2007, SEAWAT Version 4: A Computer Program for Simulation of Multi-Species Solute and Heat Transport: U.S. Geological Survey Techniques and Methods Book 6, Chapter A22, 39 p.

Nishikawa, Tracy, 1998, A Simulation/Optimization Model for Water-Resources Management, Santa Barbara, California: U.S. Geological Survey Water-Resources Investigations Report 97-4246, 99 p.

Nishikawa, Tracy and Martin, Peter, 1998, A Postaudit of Optimal Conjunctive Use Policies, in Loucks, E.D., ed., Water Resources and the Urban Environment, Chicago, Illinois, June 7-10, 1998, Proceedings: Reston, VA, American Society of Civil Engineers, p. 591-596.

Schmid, Wolfgang, Hanson, R.T., Maddock, III, and Leake, S.A., 2006, User Guide for the Farm Process (FMP1) for the U.S. Geological Survey's Modular Three-Dimensional Finite-Difference Ground-Water Flow Model, MODFLOW-2000: U.S. Geological Survey Techniques and Methods 6-A17, 127 p.

Zheng, C. and Wang, P.P., 1999, MT3DMS, A modular three-dimensional multispecies transport model for simulation of advection, dispersion and chemical reactions of contaminants in groundwater systems: Documentation and user's guide: U.S. Army Corps of Engineers Contract Report SERDP-99-1, variably paged.

Job Hazard Analysis For New Projects

- **Check the numbered box(s) for all significant safety concerns this project should address. Significant safety concerns are commonly those that require training, purchase of safety equipment, or specialized preparation to address potentially hazardous conditions.**
- **Identify any unlisted safety concerns at bottom of the page.**
- Provide details on the back of this page.

Proposal Number_______________________

Project Title (Short):

Project Chief or Proposal Author:

√	Safety Concerns
1.	Wading, bridge, boat, or cableway measurements or sampling
2.	Working on ice covered rivers or lakes
3.	Measuring or sampling during floods
4.	Well drilling; borehole logging
5.	Electrical hazards in the work area
6.	Construction
7.	Working in remote areas, communication, office call in procedures
8.	Ergonomics, carpal tunnel syndrome
9.	Field Vehicles appropriate for task?- Safety screens, equipment restraints.
10.	All terrain vehicles, snowmobiles
11.	Helicopter or fixed wing aircraft usage
12.	Site access
13.	Hypothermia or heat stroke
14.	Hantavirus, Lyme Disease, Histoplasmosis, Pfiesteria, Others?
15.	Contaminated water with sanitary, biological, or chemical concerns
16.	Immunizations
17.	Laboratory or mobile laboratory. Chemical hygiene plan.
18.	Hazardous waste disposal
19.	Hazardous waste site operations
20.	Confined space
21.	Radioactivity
22.	Respiratory protection
23.	Scuba Diving
24.	Electrofishing
25.	
26.	
27.	
28.	

Box No.	For each numbered box checked on the previous page, briefly: A. Describe the safety concern as it relates to this project. B. Describe how this safety concern will be addressed. Include training, safety equipment and other actions that will be required. C. Estimate costs.
7	Although the study area is not remote, CAWSC call-in procedures apply and employees will check-in with a CAWSC designated employee at the end of each work day.
9	California CAWSC field vehicles will be use to collect data for this project. The field vehicles are maintained by the CAWSC for this purpose, inspected by the CAWSC safety office and contain appropriate safety screens and other equipment. There will be no additional cost to the project.

Discussed job hazard analysis (JHA) with CAWSC Collateral Duty Safety Officer **Yes__x__ No____**

and/or copy of JHA given to Collateral Duty Safety Officer **Yes___x_ No____**

CAWSC Chief ________________________________ **Date** __________

Regional Program Officer ________________________________ Date ___________

Optimal Groundwater Sustainability, Santa Barbara, CA: Executive Summary

Problem

Prior to 1997, local surface water and groundwater supplied all of the water supply for the city of Santa Barbara (about 120 miles northwest of Los Angeles). Excess pumping of groundwater during times of drought resulted in saltwater intrusion in Storage Unit I of the Santa Barbara groundwater basin. Since 1997, State Water Project (SWP) water has been delivered to the city, which has reduced the demand for groundwater. However, future urban growth, limits on the supply of imported water, and the decreased storage capacity of Gibraltar Reservoir due to sedimentation will increase the future demand for groundwater, especially during times of drought. There is a need to know the sustainable yield of the local groundwater basins in order to optimally utilize the available water-resources during periods of drought.

Study Objective

The city of Santa Barbara has requested that the U.S. Geological Survey (USGS) undertake a cooperative water resources study to develop an understanding of the sustainable yield of the Santa Barbara groundwater basins (Foothill subbasin, Storage Unit I, and Storage Unit III) under current (2010) and future conditions. In addition, the study will develop decision rules, which will allow the city to evaluate the current state of the groundwater basins by measuring water levels and chloride concentrations at key wells.

For this work, sustainable yield is defined as the volume of groundwater in storage that can be pumped without causing excessive drawdowns or chloride concentrations at selected wells. The sustainable yield changes with time and is dependent on water levels in the different groundwater basins and the location of the seawater front in Storage Unit I. The sustainable yield of the Santa Barbara area was at a maximum in the early 1940s, prior to significant groundwater pumping. Groundwater pumping results in water-level declines, which reduces the available groundwater in storage and can result in the landward movement of the seawater front if water levels decline below sea level adjacent to the coast. During prolonged nonpumping periods, water levels recover to near pre-development conditions; however, the seawater front is much slower to return to pre-development conditions.

Current (2010) sustainable yield

The sustainable yield for the Santa Barbara groundwater basins will be estimated for current (2010) conditions using a three-dimensional density-dependent solute transport model (solute-transport model). The solute-transport model simulates the movement of groundwater and the transport of chlorides related to seawater intrusion. The model will provide the city the ability to predict future water levels and the location of the seawater intrusion front in response to different recharge and pumping scenarios.

The solute-transport model will be developed from the groundwater-flow model that was previously developed by the USGS. The groundwater-flow model consists of two model layers. The solute-transport will require additional model layers to simulate the density affects of seawater intrusion. Water levels and chloride concentrations are dependent on the quantity and distribution of historical recharge and pumping; therefore, the solute-transport model will be used to simulate groundwater conditions from pre-development conditions (1947) to 2010. The distribution and quantity of natural recharge calibrated for the groundwater-flow model will be used in the solute-transport model. Municipal pumping has been recorded for most of the simulation period, and where records are available the values will be used directly in the model. Missing periods of record will be estimated based on climate records and historic pumping patterns. In the Foothill subbasin there is unreported agricultural pumping which may be a large percentage of the pumpage in this basin (William Ferguson, city of Santa Barbara, personal commun., 2009). For this project, the Farm Process (Schmid and others, 2006) will be used to estimate the unreported agricultural pumpage. The Farm Process estimates agricultural pumping on the basis of crop type, climate, and soil type. The model will be calibrated to observed water levels and chloride concentrations.

The calibrated solute-transport model can be used to simulate the volume of groundwater that can be pumped from the Santa Barbara groundwater basins without causing drawdowns or chloride concentrations to exceed specified levels at selected monitoring points. The drawdown and chloride concentration metrics will be specified by the city of Santa Barbara. The city operates more than 20 municipal supply wells that pump water from different locations and different depths in the groundwater basins. Theoretically there are infinite combinations of pumping that will satisfy the city's metrics. Therefore, the solute-transport model will be used in conjunction with optimization techniques to determine the optimal pumping strategy that maximizes the sustainable yield while satisfying the city's metrics.

Future sustainable yield

The sustainable yield in 2011 will be dependent on how much groundwater is pumped in 2010 and recharged in 2011. If no groundwater is pumped, then the sustainable yield in 2011 will be greater than the computed sustainable yield in 2010 because recharge to the groundwater basins will cause groundwater levels to rise which will increase the groundwater in storage. In addition, if water levels are above sea level near the coast, the seawater front will be pushed seaward, which will increase the volume of freshwater in Storage Unit I. However, if the city pumps the total computed sustainable yield in 2010, then the sustainable yield in 2011 only would be equal to the volume of groundwater that recharged the groundwater basins in 2011.

If one could predict the future climate (wet or dry cycles), then effectively utilizing the available groundwater resources would be a relatively simple exercise. For example, if the climate was currently in the last year of a dry period and future years were going to be wet, then pumping a large quantity of the sustainable yield would be a reasonable risk. However, if the climate is entering the first year of a multiple year dry period, pumping a large quantity of the sustainable yield would be a poor management decision. Unfortunately, predicting the future climate is an uncertain science at this time. One way of evaluating the probability of future climatic conditions (wet/dry cycles) is to utilize the historic climate record. This study will collect and analyze precipitation data to identify average and extreme "dry-wet-dry" cycles. In addition, the question "if I'm in a drought this year, what is the probability that a drought will occur next year?" will be answered (transition probabilities). The simulation-optimization model will then be used to identify future sustainable yield assuming different climate cycles.

Developing decision rules to evaluate the current state of the groundwater basins

The solute-transport model will be used in conjunction with optimization techniques to develop decision rules to evaluate the current state of the groundwater basins. The decision rules for Storage Unit I will be developed by determining the one-year sustainable yield for varying initial chloride concentrations at key monitoring wells. Average chloride concentrations at key monitoring wells, representing potential measured values, will be simulated and the optimization problem will be solved for varying chloride-concentration constraints (e.g., 10, 25, 50, and 75 percent chloride). This will yield a family of curves that define the maximum amount of pumping for a given initial chloride-concentration distribution and chloride-concentration constraints (fig. 1). Figure 1 is an example of what the decision-rule curves may resemble, i.e., the actual curves may be concave, undulating, or linear.

The decision rules for Storage Unit III and the Foothill basin will be developed by determining the one-year sustainable yield for varying initial water levels at key monitoring wells. The allowable hydraulic head will be varied with the minimum value equal to the middle elevation of the perforated interval of the shallowest production well in a subbasin. This constraint will be determined after consultation with city personnel. This will yield a family of curves that define the maximum amount of pumping for a given allowable hydraulic-head constraint.

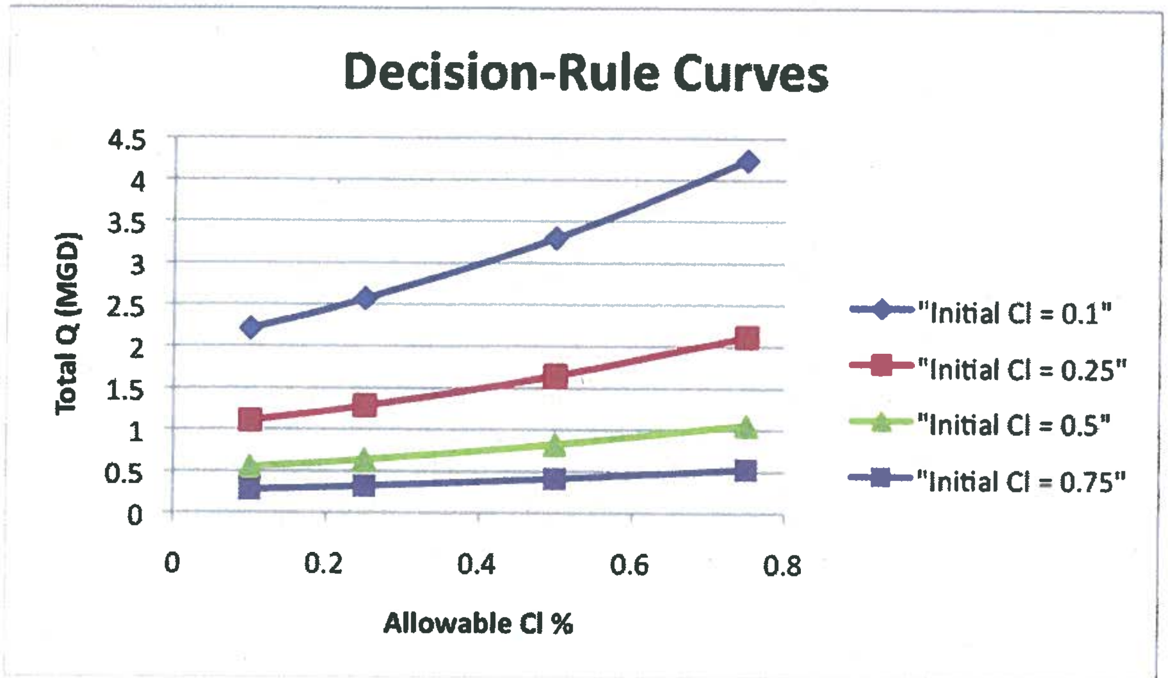


Figure 1: Example Storage Unit I decision-rule curves

Budget

Fiscal Year		2010		2011		2012		Total
!"# $	%&'(!"#$	SB	USGS	SB	USGS	SB	USGS	
1. Current Sustainable	Develop Solute Model	$102,500	$50,000					$152,500
Yield	Simulations	$31,000	$15,000	$13,400	$6,000			$65,400
2. Future Sustainable Yield				$64,000	$33,000	$15,500	$7,000	$119,500
3.Decision Rules				$58,000	$30,000			$88,000
4. Report						$61,000	$30,000	$91,000
Total		$133,500	$65,000	$135,400	$69,000	$76,500	$37,000	$516,400

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